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ABSTRACT

This report investigates the feasibility of including computer aided design (CAD) materials in engineering courses. Section 1 briefly discusses the inevitability of CAD being adopted widely by British industry and the consequent need for its inclusion in engineering syllabi at all levels. A short description of what is meant by CAD follows in section 2. Section 3 discusses some components of an integrated CAD system in more detail, particularly drafting systems that are more advanced and more immediately attractive than other elements of CAD. Three major problems in introducing CAD into courses are outlined in section 4: lack of cheap hardware and commercial software, lack of educational software, and lack of staff expertise. Section 5 considers three broad categories of CAD user (systems designer, specialized user, naive user) and their different training and educational requirements. Appendixes include a fairly comprehensive list of CAD topics for inclusion in courses, information on help available through the West Midlands Regional Office Departments of Industry and Trade, and a short glossary of terms used in the paper. (YLB)

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An Occasional Paper

Computer Aided Design in FE

Some suggestions on the inclusion of CAD
topics in Mechanical Engineering courses

P. C. Ingham

City of Birmingham Polytechnic

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Dear Sir/Madam

COMPUTER AIDED DESIGN IN FE

I enclose herewith a copy of an FEU occasional Paper commissioned by us from Dr Peter Ingham of City of Birmingham Polytechnic. It is intended to give guidance to those concerned with the introduction of this vital development into technical curricula, and whilst specifically related to mechanical engineering, it should also prove useful to those in other disciplines.

Dr Ingham considers as inevitable the widespread adoption of CAD by British Industry. Millions of pounds are now being invested by the Government in promoting awareness and supporting schemes to increase the use of CAD in both mechanical and electrical engineering. Further education has therefore an obvious role to play in this development if it is to remain a significant contributor to technological updating. Like other aspects of new technology, in spite of falling costs, the expense of acquiring the necessary equipment and developing appropriate software is a daunting constraint for many colleges on reduced budgets. Some guidance on this and other practical problems is given in Section IV and Dr Ingham concludes that some form of software "clearing house" may be a worthwhile investment.

After an introduction to the concept of CAD and its elements, the document discusses the probable educational needs of systems designers, specialist users and "naive" users, and whilst their overall needs are distinct, Appendix A suggests a possible basic curriculum that could be adapted for use in many engineering courses. A staff development strategy is described and a brief glossary of terms is also provided.

The FEU has a small but expanding portfolio of work associated with new technology, to which this document contributes. Further details are available on request. Various CADMAT* Demonstration Centres are now opening as part of the DoI/CADMAT awareness programme, but these are predominantly aimed at industry rather than education. A modest amount of support from the FEU could be made available for further educational development in this or associated areas, in particular the development and dissemination of appropriate software seems now to deserve priority. In the meantime additional copies of this document are available from our Publications Despatch Centre.

* Computer Aided Design, Manufacturing and Testing.

Yours faithfully,

Jack Mansell

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- 1 reviewing the range of existing curricula and identifying overlap, duplication and deficiencies
- 2 determining priorities for action to improve the total provision and suggesting ways in which improvement can be affected
- 3 carrying out specific studies, helping with curricular experiments, and contribution to the evaluation of objectives, and
- 4 disseminating information about the process of curriculum development in FE.

The publications in this series of Reports are intended to inform teachers and others and to stimulate professional discussion about matters of concern to the FE service.

The views expressed are those of the authors and are not necessarily those of the Unit's Board of Management. A limited number of extra copies of this report are available from

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Computer Aided Design in Further Education

Introduction

1. This report is an attempt to investigate the feasibility of including CAD material in engineering courses. It briefly discusses the inevitability of CAD being adopted widely by British industry and the consequent need for its inclusion in engineering syllabi at all levels.

2. A short description of what is meant by computer aided design follows. Some of the components of an integrated CAD system are discussed in more detail, particularly draughting systems which are for various reasons more advanced and more immediately attractive than other elements of CAD.

3. Problems arising in the inclusion of CAD in syllabi are outlined. It is concluded that these are not insuperable but that a careful investigation of the cost of installing commercial hardware and software would be beneficial. Some guidance on current prices of modest equipment is given based on a limited amount of research. Prices quoted are correct for 1982. A further aid would be the creation of a software clearing house for the distribution of CAD software and the dissemination of information about work in progress.

4. A fairly comprehensive list of CAD topics for inclusion in courses is appended. Although this is broadly in TEC style, it can be tailored to suit courses at various levels.

Finally, a short glossary of some of the more esoteric terms used in the report is included.

5. Much of the information in the report has been obtained from various users of CAD systems. I should particularly like to single out Ed Lambourne of Delta Computer Aided Engineering Ltd., Mr E. Blakely of Joseph Lucas Ltd., Mr Rimmer of Cincinnati Milacron Ltd. and Roy Eddington of Dunlop Ltd. Acknowledgements to Delta CAE Ltd. for Figures 2 and 3 in the report, COMPEDA Ltd. for Figure 3 and Applied Research of Cambridge for Figure 5.

| Should we include CAD in our Design Courses?

6. CAD is considered by some authorities to be probably the most significant advance in engineering manufacture in modern times; it is thought that it will have a major effect on designed and manufactured products by the 1990's and will influence the economies of the manufacturing nations in the next century.

7. An informal survey carried out with TEC and part-time BSc students indicates that 20% of the students work at firms who use computer-aided draughting systems.

Ref 1 quotes estimates of the growth of CAD systems . . . an extract from this comprehensive study is that by

"1985 CAD techniques . . . will be used for 25% of the new assemblies designed.

1987 CAD techniques . . . will become adopted by 20% of the companies.

1990 CAD techniques will be used for 50% of the new assemblies designed".

8. A more popular source (Ref 2) claims that in the USA, the number of CAD/CAM installations grows by more than 30% per year in spite of a sluggish economy. Other sources quote remarks from managers such as "once you have a computer aided draughting system, you never go back" and "it paid for itself in 2 years".

9. It seems clear that: (a) the use of CAD is expanding in industry in the USA, Japan, West Germany and as far as can be judged, in this country also, and (b) this expansion will continue, at least to the end of the century. Of course there are problems, mainly due to the early stage of development of the field (Ref 3 gives an account of these).

10. Although this paper is not an apology for the introduction of CAD into engineering firms, it might be appropriate to mention just some of the more cogent reasons.

- (a) At its most primitive, CAD relieves engineers of much of their more repetitive work, enabling the more creative aspects of design to be given more time.
- (b) It is reasonably well established that even current systems improve productivity – the factor of improvement is variously claimed as 3 to 10.
- (c) The use of CAD reduces the need for specialists.
- (d) The integrative nature of CAD permits the design process to be carried out in a much more systematic way.

11. The question of whether we include CAD/CAM techniques in our courses is a separate issue. Some educationalists consider that there are few (if any) new principles in CAD/CAM and that since it is only a tool to use in the design process, it would be pointless to spend much valuable class contact time on it. (Ref 4 gives some opinions of this nature in more detail). It is certainly true that many aspects of computing that we teach today may be relegated to the schools by the end of this decade. Although we teach subjects such as "Computer Appreciation" or "Computer Awareness" in many courses, it is almost certain that it will soon be unnecessary to do so. Over the last two years, the number of students possessing home computers or using larger computers at work has increased and shortly the majority of students will have as much need for computer awareness courses as they now have for the ubiquitous "How to use a calculator" subject which was also taught up to about five years ago. If CAD/CAM is a tool to be used by engineers, need we spend longer on it than we currently spend on teaching the effective use of draughting machines?

12. There are several counter arguments to this point of view. It is not envisaged that there will be any startling breaks through in CAD in the next few years. At the moment, the benefit obtained from using the system is intimately connected with the skill and knowledge of the user. Surely it is our duty to provide industry's needs and certainly there will be a need for CAD expertise.

Again, we have a duty to the student. Many of our students because of the nature of industrial structure in this country come from small firms who may still be unlikely to have CAD/CAM systems for several years. The only place where students may be exposed to new technology is the academic institution.

Even in large firms, it is unlikely that more than half a dozen work-stations will be installed – the average number today seems to lie somewhere between 1 and 3, although some firms with a high degree of commitment to CAD have considerably more – Baker Perkins Ltd have 25. The use of the CAD system is then restricted to a designing elite and the normal rank and file designer gets little chance to obtain any hands-on experience of the system.

13. Currently, most courses on CAD/CAM (and there are a few mentioned in the Computer Users' Year Book 1981) are

run by commercial companies. These are normally very expensive; often as much as £1000 for a three-day course. Without discussing the value of these courses, it might be suggested that the small to medium firm would be served better by courses in an academic institution which would at least be cheaper even if the equipment used were more primitive.

14. It seems probable that CAD/CAM systems will become far more complex towards the end of the century. The principles mourned by some of the antagonists of teaching CAD/CAM will emerge – if they have not already done so. We shall then be in the same state of unpreparedness as we were when NC equipment became more complex and common with no one capable of teaching the subject.

15. Finally, Ref 4 states that CAD/CAM courses are commonplace in the USA and most of the countries in Western Europe provide many courses, even some of the less technologically developed ones – the University of Trondheim has had a CAD course for two years. It is essential that we keep our place in the technological league and we can only do this by creating a pool of highly trained technicians and engineers who are accustomed to high-technology and can respond rapidly to advances in it.

II What is Computer-Aided Design?

16. A useful definition may be found in Ref 4.

"CAD/CAM is an interactive computer system used primarily for the generation, storage and utilisation of geometric and graphical information to assist in the solution of engineering and manufacturing problems". The salient points of this definition will be discussed in this section and given a fuller treatment in Section III.

Interactive Computer Systems

17. Computers may be used in batch mode or interactive mode. In the former, the user has no contact with the computer between the time that the job is initiated and the time that either an answer is obtained or the program terminates prematurely due to error. In interactive mode, the user has contact with the program while it is running and can alter data and the path of calculation; the process is a joint venture. This is eminently suitable to design which is an interactive process. The designer can make an initial estimate of the configuration of the part, view it, analyse it and successively refine it. Humans are intuitive, imaginative and can draw on experience. Computers are fast and accurate calculators, obey rules rigorously and can store and retrieve large amounts of data. Using computers interactively allows these two sets of qualities to complement each other. A more detailed argument will be found in Refs 5 and 6.

Generation of Geometric and Graphical Information

18. Ideally, a CAD system should allow a user to set up a model of a manufactured part in a convenient and comprehensive way. The model should consist of all the relevant information about the part including shape, material properties, surface texture properties, cost and so on. Many systems allow this to be done to some extent, the user setting up a geometric model of the part interactively, the shape being built up section by section. A difficulty is that the three-dimensional model is displayed on a two-dimensional screen and so the designer needs considerable practice to use the system easily and productively. Advances in stereoscopy and holography may improve this key area in CAD but it seems that most currently available systems are not easy to use.

Storage of Geometric and Graphical Information

19. There are various methods of creating models of parts. Surfaces may be represented by patches – the surface is built up like a patchwork quilt. Solids may be modelled by primitives – common solids such as parallelepipeds, cylinders and spheres may be aggregated to build up the part. Another system, which is more flexible than it sounds, permits irregular sections through solids to be threaded on a curved spine. Each system of representation has its protagonists and this is an area which is changing rapidly. Most commercially available systems permit most engineering solids to be modelled precisely but there is plenty of room for improvement in the field. The method of storage depends in detail on the geometric modelling system used but in general some data structure is used to store the form parameters.

Utilisation of Geometric and Graphical Information

20. When the geometric model of the part has been created to the designer's satisfaction, it may be analysed to discover whether it is functionally satisfactory. If not, the shape may be altered interactively. The aim of the designer is to optimise the part; material should be minimised and appropriate for operating conditions, the part should fit inside its operating envelope, it should function correctly and so on. In order to achieve this optimal solution, various analytical models may be used. These are specialised to the problem, but common analytical models are Finite Element Analysis systems for performing stress and vibration analysis, Material Selection packages for the matching of material properties and operating requirements and Machine Element Design packages for such applications as spur gearing analysis, design of close-coiled helical springs and bearing design.

It should be possible to generate conventional engineering drawings from the three-dimensional model. Since the model must be capable of being viewed from any aspect of the screen, it seems a simple matter to generate orthographic views of it. Often, though, draughting is treated as a separate system. Probably the reason for this is that it is considered by some firms that full CAD systems

are not sufficiently developed to provide productivity increase commensurate with their cost. Draughting systems are well-developed and it is only necessary to witness an experienced draughtsman using a well designed system to appreciate the benefits that are possible.

III The Elements of an Integrated CAD System

21. An integrated CAD system is shown in Fig 1. Parts of this will be described from the user's point of view.

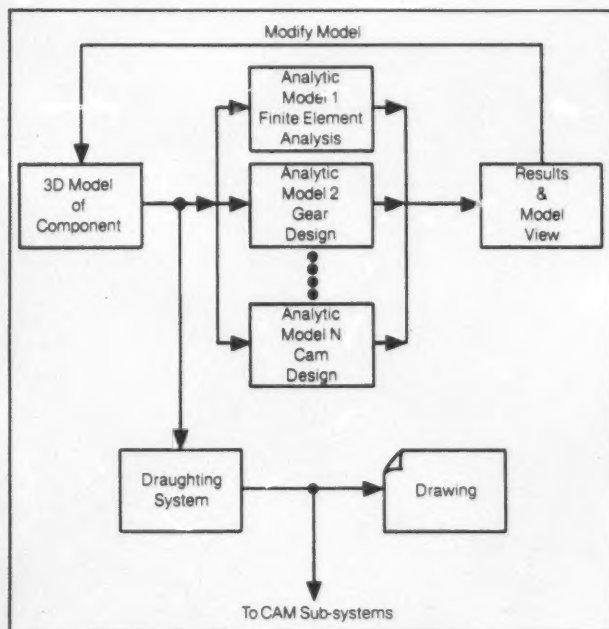


Fig 1. Integrated CAD System

Geometrical Modelling Systems

22. These allow the user to describe the shape of the part in three dimensions. It may be rotated, magnified and viewed from different aspects and changed interactively. Often data such as superficial area and volume may also be calculated. The shape information may be suitable for input to other sub-systems such as finite element analysis systems and machining simulation systems. Some systems permit a numerical control tape to be produced so that a prototype may be cut in expanded polystyrene or similar material.

As with all abstract models, the degree of refinement of the model is determined mainly on economic criteria. It would clearly be desirable to present as realistic a view of the part as possible which would be useful for deciding on the aesthetic appeal of the part. Some of the more advanced graphic systems permit astoundingly realistic

views to be produced; colour, shading, texture and specular reflection may be added and objects may be viewed stereoscopically. Good examples may be seen in Ref 7. However, most of these use very costly equipment and a good deal of computing time and it is difficult to envisage their use in engineering systems for some time. Some features of interest in engineering parts are proving difficult to represent satisfactorily – manufacturing tolerance and surface finish are examples.

A good review of geometrical modelling systems may be found in Ref 8. Examples of output from commercial packages are Figs 2 and 3.

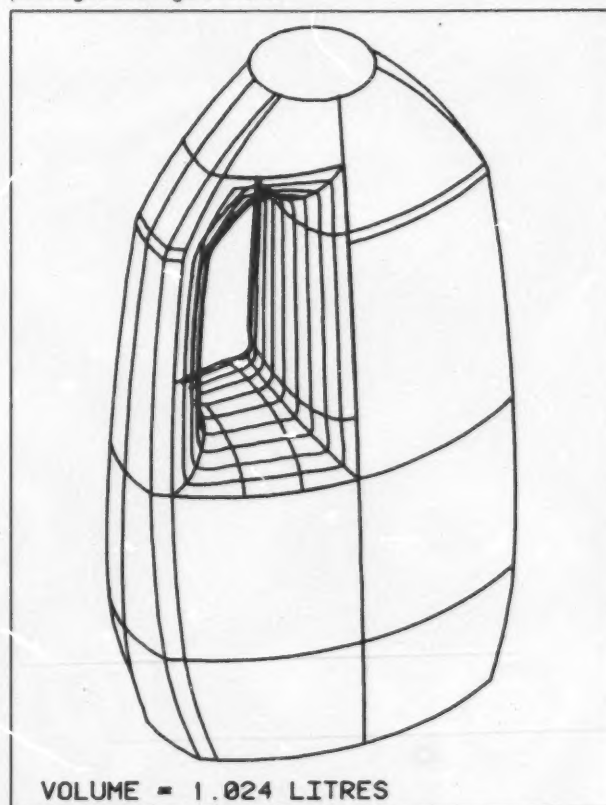


Fig 2. Output from DUCT, surface modelling system

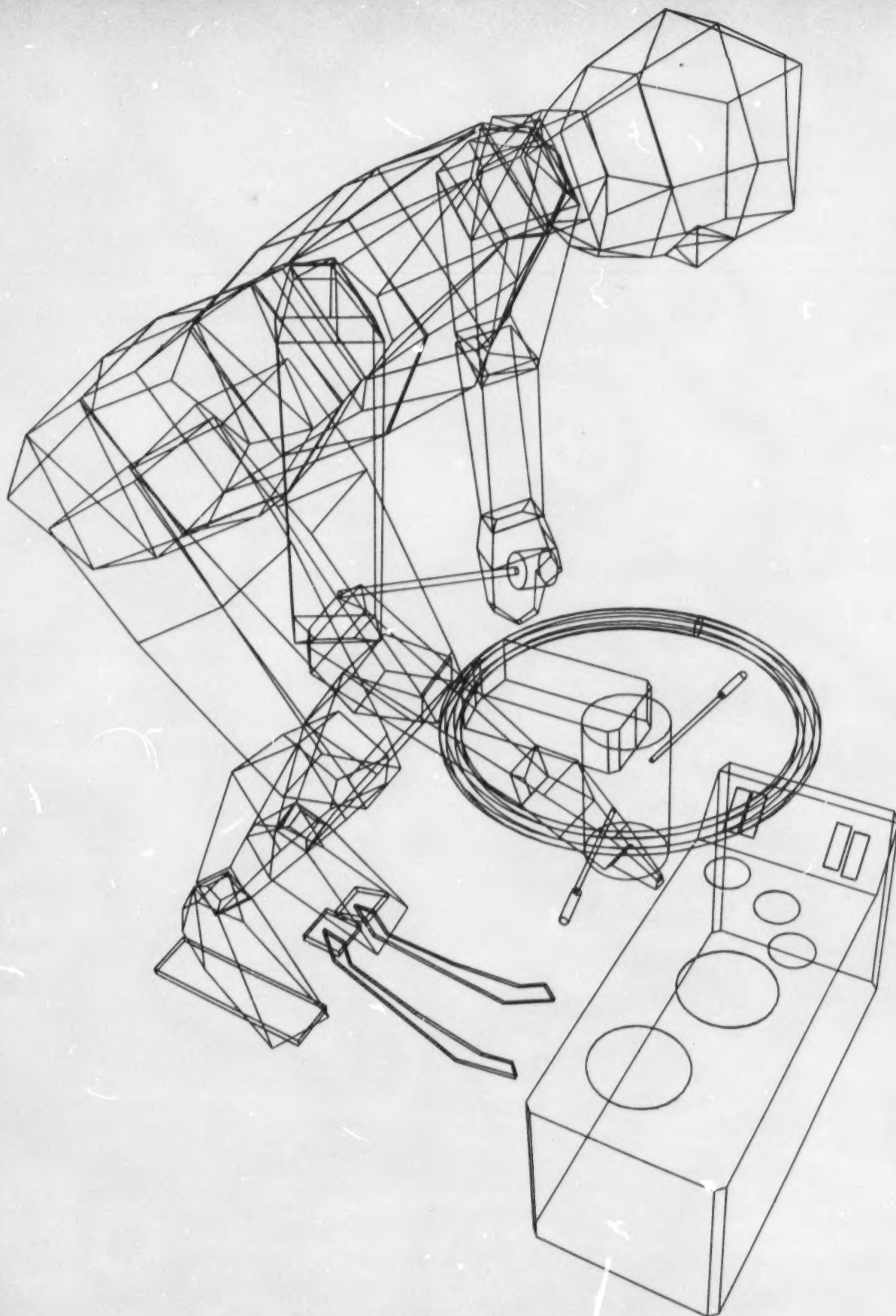


Fig 3. Output from SAMMIE, anthropometric and 3D modeling system

Analytical Models

23. These permit the functional analysis and optimisation of the product. The type of model will be specialised to the particular application but some examples will be described.

Finite Element Packages

24. The part is built up from a standard set of elements which are peculiar to the system. These elements may be patch-like for plate applications and blocks for 3-D applications. Sufficient are used to approximate to a continuous form; a compromise being made between accuracy of results and processing time. Loading is applied to the model together with appropriate constraints. Continuity and stress conditions for the model yield a set of linear equations, usually large, which must be solved to give displacements and stresses. The results are often displayed graphically and in some applications animated. The input to a finite element analysis system is often a high overhead. This may be reduced if the system is integrated with the geometrical modelling system so that meshes can be created interactively. A standard book on this topic is Ref 9.

Machine Element Design Packages

25. Assemblies are often built up with standard elements such as close-coiled helical springs, gears, cams and plain and roller bearings. It is not often that the analysis is direct; normally iteration is required and so interactive operation is ideal. Some of these do not seem to fit in naturally with the integrated system as described; it would not be appropriate to design a roller bearing using the geometrical modelling system. However, it is advantageous if the bearing were held in geometrical form, particularly for the production of assembly drawings. Some systems enable such shapes to be held in parametric form so that dimensions may be varied to suit the application. Packages exist for the design of most of the common machine elements.

Kinematic Analysis Packages

26. Mechanisms built up from linkages joined by pinjoints and sliders are commonly used in engineering, notably in

wrapping machinery and robots. Traditionally, linkages of this kind have been analysed graphically to find values of interest such as velocity, acceleration, inertia forces and the effect of tolerance. Analysis of mechanisms is difficult; synthesis is even more so, requiring a good deal of trial and error. Clearly, this is a suitable application for interactive solution with graphical input and output.

Ergonomic Models

27. Many manufactured products are designed for human use and it is then useful to have a flexible human model so that the product may be tailored to fit the ergonomic requirements of the user. A popular ergonomic model is Compeda's Sammie.

Draughting Systems

28. These are probably the most easily used and beneficial elements of a CAD system. Since their use is becoming quite common, the action of a typical system will be described in detail. The hardware required is:

- (i) a graphics screen, often a direct view storage tube such as the Tektronix 4014 or equivalent. The drawing is performed on the screen, a cross hair cursor being used by the designer to point to features of interest, control being by thumbwheels or a joystick;
- (ii) a bit pad or graphics tablet. The user may point to areas of the flat surface of the pad with a stylus and the position of the area pointed to may be transmitted to the computer. Often the bit pad surface is divided into areas with significant meaning to the draughting system. This is called a menu and menu options may be picked with the stylus. On some systems, part of the bit pad is reserved for sketching, the motion of the stylus being replicated on the screen. This is a very natural way of using the system;
- (iii) a plotter. In a realistic system, this will be capable of plotting drawings up to A0 size and will have various thickness of pens so that for instance, the form of the part and its dimension lines may be differentiated.

29. The procedure for drawing a part is as follows:

The image on the screen may be drawn on any of a number of conceptual planes, often as many as 256. One of these may be used for construction lines; it is made invisible when the drawing is plotted. The user lays out the

construction lines on this plane much as is done on the normal drawing board, but much more conveniently. The part may then be drawn using options from the menu and inputting sizes on the normal alphanumeric keyboard. With a minimum of practice this can be done faster than by conventional means, since portions of the drawing may be copied, rotated, mirror imaged, changed in scale and dragged into other positions. Lines may be drawn in full or in various dashed and chain-dotted styles. Fillets and chamfers may be easily added and sections may be hatched. Conventional representations of threads, welds, knurling, etc., may be added using standard options. On satisfactory completion of the drawing, dimension lines and toleranced dimensions may be drawn conveniently – the nominal sizes being known to the system. Finally, text in various fonts and sizes, standard notes and other items such as company logos may be added to the drawing. A typical menu card is shown in Fig 4. A close inspection of this will reveal the undoubted power of the system.

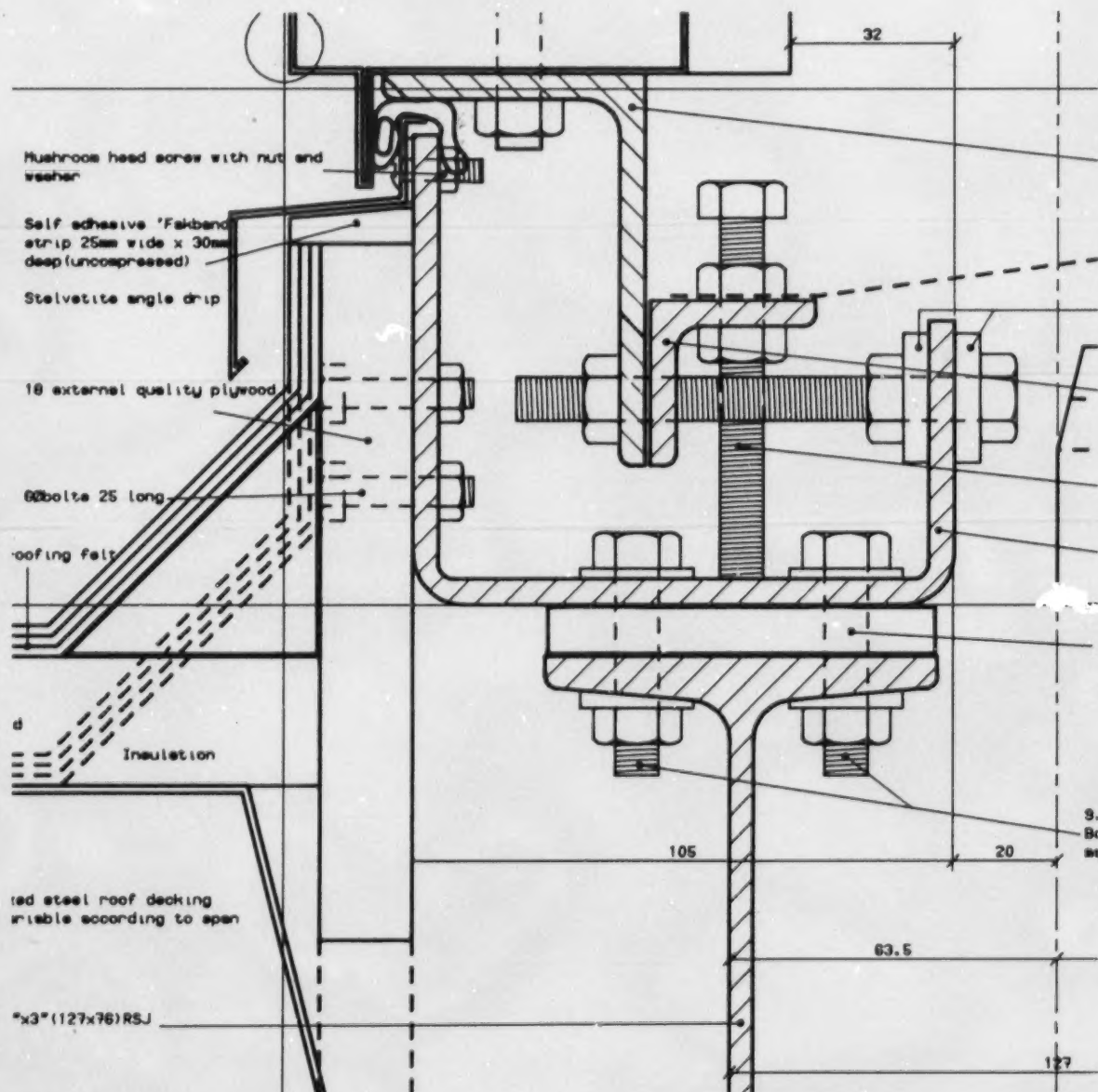
30. Drawings may be plotted and archived in the computer backing store so that they may be retrieved at a later date, possibly for rapid amendment and correction. More advanced systems permit parameterisation of parts so that key dimensions may be changed on standard items. Parts lists and costing information may also be stored and retrieved.

31. Draughting systems are satisfying and simple to use and it is certain that their use improves drawing productivity – a conservative estimate is an increase by a factor of 3. This to a large extent depends not on the computer awareness of the user, but on the draughting expertise. The complexity of the part is also a factor.

32. Some systems have been designed so that the drawing information may be used as input to a CAM system. The machining of the part can be simulated and checked on the screen and a NC tape produced.

Drawings produced by Draughting Systems may be seen in Fig 5.

VIEW SELECT		FACILITIES		SYMBOL	
1 SELECT VIEW NUMBERED	17 DELETE VIEW	1 REDRAW	17 PLOT	1 DEFINE	17 CHANGE TYPE on drawing
2 CHANGE ACTIVE VIEW	18 DISPLAY VIEW TEXT	2 RESET USER ORIGIN	18 EDIT SYMBOLS	2 RETRIEVE	18 TRANSIENT
3 ADD VIEW LINES	19	3 REVOKE	19 AND HATCHING	3 REPAUSE	19 PERMANENT
4 IGNORE VIEW LINES	20 DISPLAY VIEW SYMBOLS	4 STATUS	20 DIAGNOSTICS	4 DELETE FROM FILE	20 MAKE PERMANENT on drawing
5 ADD VIEW BOSS	21	5 TOLERANCE	21	5 PRODUCE CHART	21 UNLINK
6 IGNORE VIEW BOSS	22 TOLERANCE TO ACTIVE	6 TOLERANCE COARSE	22 SCREEN	6 EXAMINE LIST	22 UNLINKED
7 HIT SELECTED VIEW	23 VIEW ONLY	7 MENU	23 SMDI	7 IGNORE dimensions	23 PARAMETRIC
8 WINDOW		8 DOWNTIME	23 SCALE TEXT	8 INCLUDE	24 NON PARAMETRIC
9 PREVIOUS WINDOW		9 INITIALISE GRID	24 SMOOTHNESS	9 PUBLIC	25 EDIT SYMBOL on file
10 ZOOM		10 PAPER units	25 MOVIE/EXPERT	10 PRIVATE	26 SPECIFY NODE TYPE
11 FULL PAGE		11 STRUCTURAL units		11 SYMBOL	
12 PAPER SIZE		12 LIMITS - mm		12 SHAPE	
13 STRUCTURE SIZE		13 cm		12 FLEXIBLE	
14 MOVE VIEW		14 in		14 DEFINED	
15 CREATE VIEW		15 mm		15 SKETCH	
		16 in		15 FIXED	
		16 ft	26 STOP		
MEASURE		LINE		HATCH	
1 SET DECIMAL PLACES	17 PAPER SIZE	1 CONTINUOUS LINE	17 FILLET AUTO	1	STRUT
2 X, Y rel to	18 IDENTIFY ITEM	2 SEPARATE LINE	18 SEMI AUTO	2	FLAT
3 L, A origin	19 CALCULATOR	3 CONTINUOUS CURVE	19 MANUAL	3	CYLIND
4 X, Y rel to		4 Discontinue	20 SMALL	4	PROFL
5 L, A centre		5 3 points	21 LARGE	5	PROFS
6 LENGTH of line or arc		6 PARALLEL/TANGENT	22 SET FILLET RADIUS	6	PARAL
7 ANGLE of line or arc		7 PERPENDICULAR/NORMAL	23 FIXED ANGLE	7	SQUA
8 ANGLE of line rotation		8 TYPED ANGLE	24 FIXED ANGLE TOLERANCE	8	ANGLE
9 RADIUS of circle or arc		11 COMMON TANGENT		9	POSH
10 TEXT		12 PARALLEL/CONCENTRIC		10	CONCEN
11 LINE INFORMATION		13 CONTINUOUS PARALLEL		11	DATUM
12 GRID REFERENCE		14 MULTIPLE PARALLEL		12	DATREF
13 AREA		15 IGNORE		13	BOX1
14 PERIMETER		16 INCLUDE		14	BOX2
15 IGNORE				15	MBOR1
16 INCLUDE					MBOR2
TEXT		LINE TYPE		DIMENSION	
1 HEIGHT of text	17 SINGLE LINE TEXT	1 TYPE	17 CHANGE TYPE	1	TAPER1
2	18 MULTIPLE LINE TEXT	2	18 CHANGE INT	2	TAPER2
3	19 TEXT BELOW	3	19 CHANGE TYPE	3	CL
4	20 TEXT ADD	4	20 CHANGE INT	4	MACH1
5	21 SET TEXT ANGLE	5	21 FAST LINE	5	MACH2
6	22 TEXT PARALLEL/TANGENT	6	22 (TYPES 2, 3, 4)	6	WELD
7	23 CHANGE SIZE	7	23 SCALE LINE TYPES	7	BAREND
8	24 CHANGE STYLE	8	24 SCALE LINE TYPES	8	HPEND
9	25 CHANGE INTENSITY	9 INTENSITY 1		9	EXTAR
10	26 CHANGE ORDINARY PROMPT	10 INTENSITY 2		10	NUT
11	27 UNDERLINE add/delete	11 INTENSITY 3		11	SPRING
12	28 EDIT TEXT	12 INTENSITY 4		12	BEARING
13	29 LEFT	13 INTENSITY 5		13	SQUARE
14	30 CENTRE	14 INTENSITY 6		14	TRI
15	31 RIGHT	15 INTENSITY 7		15	QUAD
16		16 INTENSITY construction		16	PENT
DELETE		COPY		CONSTRUCT	
1 AREA	1 EXAMINE ARCHIVE FILE	1 AREA	1 CONSTRUCTION POINT	1	OPEN
2 LINE	2 MODIFY ARCHIVE FILE	2 AREA	2 PROJECT FROM	2	CLOSE
3 CIRCLE	3 TRANSFER VIEWS	3 CIRCLE	3 LINE/CIRCLE	3	CROSS
4 TEXT	4 TRANSFER AREA	4 POINT	4 BOX	4	DOT
5 DIMENSION	5 IGNORE	5 NO. OF COPIES	5 INTERSECTIONS	5	BIGDOT
6 SYMBOL/HATCH	6 INCLUDE	6 INCLUDE	6 INCLUDE	6	STAR
7 CONSTRUCTION LINES		7 NO. OF COPIES	7 INCLUDE	7	COFG
8 LINE BETWEEN 2 POINTS		8 INCLUDE	8 INCLUDE	8	TITLE1
9 CHAM		9 INCLUDE	9 INCLUDE	9	ALL DIM'S IN
10 IGNORE		10 INCLUDE	10 INCLUDE	10	ALL DIM'S IN
11 INCLUDE		11 INCLUDE	11 INCLUDE	11	NO UNLINK
		12 INCLUDE	12 INCLUDE	12	NO UNLINK
		13 INCLUDE	13 INCLUDE	13	NO UNLINK
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Full size detail of building junction components.

Fig 5. Output from GOS Draughting System

IV Some Practical Problems in CAD Training and Education

33. The three major problems in introducing CAD into courses are:

- (i) Lack of cheap hardware and commercial software.
- (ii) Lack of educational software.
- (iii) Lack of staff expertise.

Some solutions will be discussed.

Lack of Cheap Hardware and Commercial Software

34. An upmarket CAD system costs around £100,000 per workstation. A smaller one might cost in the region of £25,000. Clearly, this is beyond the means of the average technical college and another solution must be sought. At the expense of some convenience and practicality, the cost may be reduced as follows:

- (i) a low resolution screen may be used. The cheapest minimally acceptable for CAD use – a 512 x 512 pixel raster screen costs £1,200-£2,400. Although it is difficult to read the graphic text on a screen of this resolution, it is feasible to present demonstrations in a limited way;
- (ii) a bit pad costs less than £1,000. It may be possible to do without this since some systems allow menus to be picked on the screen;
- (iii) if a plotter is not available, then a hardcopy unit may be used. This gives a copy of what is currently on the screen typically on about A4 paper of dubious but readable quality. The cost varies with the type, but £3,000 seems to be an average value.

A minimal system would, then, cost:

512 x 512 Raster screen	£1,200
Electrostatic hardcopy unit	£3,000
Total cost	£4,200

A more acceptable system would be:

Direct view storage tube	£2,800
Electrostatic hardcopy unit	£3,200
Total cost	£6,000

35. Instead of buying the equipment outright, it is possible to rent it. The cheapest rental figure obtained is of the order of £20/£1,000 per month over 5 years, so that the second system would cost £1,440 per annum. Other figures quoted for comparable equipment are as high as £470/month, so it pays to shop around.

36. Software is also prohibitively expensive if it is bought outright. Examples are: £8,500-£12,500 (with academic reduction) for a commercial draughting system. Another factor to be borne in mind is that since this is a rapidly changing area, a software package will become outdated quite quickly. Other alternatives to purchase include:

- (i) Leasing – typically £1,800-£3,500 per annum over a 5 year period for a draughting system alone.
- (ii) Use of a bureau – timeshared system over a telephone line. The lowest figure obtained is £15/hour giving access to a draughting system, two geometrical modelling systems and a computer-aided manufacturing package. A typical mechanical engineering department might budget for 20 design classes having 5 hours/annum of CAD use. The cost of using a bureau would be about £1,500/annum. This is the most attractive option although using a bureau has its obvious disadvantages.

37. It seems unlikely that a cheaper alternative than renting hardware and using a bureau exists. The overall cost per annum is then:

(i) Say, 100 hours of timesharing system	£1,500
(ii) Rental cost of hardware	£1,440
(iii) Phone bill, stationery, part-rental of modem	£ 200
Total cost	£3,140

38. These figures are based on a limited amount of research on hardware and software available and the terms on which it may be obtained but because of the number of CAD suppliers (Ref 15 regularly publishes a list of about 70) and because of the complexity of the various renting and leasing conditions, it would be beneficial to perform an extensive study of this and other technological fields so that clearcut advice might be given to academic institutions. This would have the advantage also, that standard equipment permits portability of software.

39. Another possibility to consider is the use of a desktop standalone microcomputer with graphics screen. There are several available typically costing £10,000-£20,000. The problem here is the availability of cheap software which bears some resemblance to practical systems. At least one manufacturer offers a rudimentary draughting system free with such a machine but it is unlikely that any desktop machine could support other desirable sub-systems such as geometrical modelling packages. A good deal of work has been performed on CAD on small

machines at the University of Aston and there is at least one CAM package which may be used on the Commodore PET with high resolution graphics chip.

It is interesting to note that the budgeting for CAD courses in the USA is \$200/student per semester.

Lack of Educational Software

40. Commercial software is aimed at running large, complex jobs; it is generalised with many facilities which are useful in a real environment, but tend to obscure the basic structure of the system. A good example is in the Finite Element analysis field. If a large, complex part is being analysed, the input data needs careful design and takes up the major part of the user's time. Often separate pre- and post-processors are bought to facilitate the submission of input data and the analysis of output. For class use, presumably, the aim is to teach the principles of the method; large jobs may be used for demonstrations, but for student practicals, it is likely because of time limitations, that the jobs run will be simple. In this case, the housekeeping overhead of using the system will outweigh the actual data input, processing and output. Clearly, a small applications package tailored to educational use would be beneficial. It is almost certain that many small systems of this kind have been developed in academic institutions. Often program listings are given in textbooks — Ref 10, for instance.

41. An obvious requirement is some sort of clearing house for the distribution of didactic software. Its functions would be:

- (i) the provision of an information bulletin, say monthly, giving details of current programs on offer and work in progress;
- (ii) the validation of programs and provision of well-written documentation;
- (iii) the distribution of available programs for a nominal fee covering the expense of reprography, postage, secretarial work and storage medium;
- (iv) the co-ordination of programming in specialised fields so as to minimise duplication of effort. This might best be organised on a regional basis possibly within the MEP regional structure.

42. It might well be that some of the applications programs would be useful to small firms.

Lack of Staff Expertise

43. Many engineering departments have staff who are skilled in the more traditional aspects of engineering but lack experience in more modern fields such as CAD, CAM and robotics. Often secondment is impossible — there are few courses in these fields and those that do exist are generally expensive. For some reason, there is also a lack of good textbooks at the moment; possibly because the principles of CAD have not yet been formulated. There are a few CAD journals and magazines but these consist in the main of superficial descriptions of commercial packages or papers of a highly technical nature. The main journals are listed in the references.

44. The following is an account of how Birmingham Polytechnic, Department of Mechanical and Production Engineering has tackled the problem; this is part of a rolling Staff Development Programme.

- (i) A list of staff who might profit from exposure to CAD/CAM techniques was prepared.
- (ii) The Regional Director (Industry) of the Department of Industry was invited to discuss our needs and advise us. With his help, we prepared a list of local firms using CAD/CAM techniques who might be willing to assist. These were manufacturing companies such as Joseph Lucas Ltd and a local firm specialising in the use, design and marketing of CAD/CAM systems: Delta Computer Aided Engineering Ltd.
- (iii) We liaised with the firms and arranged a programme of visits and short term staff placements. Placement was for upwards of one week either for a continuous period or at regular intervals.

It was encouraging to experience the sympathetic assistance of the Department of Industry, the ready co-operation of industry and the willingness of the staff to participate.

45. The Department of Industry support a CAD/CAM scheme which might be of interest in this connection. A leaflet describing this and other services offered is appended. A more detailed treatment may be found in Department of Industry leaflets — Refs 11 and 12.

V Education in Computer-Aided Design

46. It is useful to consider three broad categories of CAD user (Ref 16). Each of these have different training and education requirements.

The Systems Designer

47. This category of CAD user will provide programs. This does not necessarily mean that these will be designed entirely from scratch; for instance, a gear design package might well use an existing commercial finite element package with mesh generation facilities specialised to the analysis of involute profiled forms.

48. Often, advances in computer theory are initiated from the more mathematical disciplines and seminal computer systems designed by mathematicians. The theory after a while becomes lore and subsequent systems designed by persons closer to the disciplines for which the systems are intended. It is commonly found that such systems are more user-friendly, reliable and better documented.

49. Ideally, the CAD systems designer should:

- (a) be thoroughly aware of the capabilities of currently available hardware and software. A knowledge of software engineering is essential – possibly languages more suitable to CAD and graphics applications may be forthcoming instead of the ubiquitous but often inappropriate FORTRAN.
- (b) Understand the theory of computer graphics. Much of this is mathematical but the mathematics involved is mainly of the kind understandable by engineers and computer scientists. Techniques in graphics are advancing quickly and it is essential that the systems designer should be, if not on the frontiers of knowledge, at least within hailing distance, since the leadtime between research and practice in this field is short. This implies, as in other areas of specialised technology, periodic re-training.
- (c) Have a broad engineering background. A difficulty generally experienced in implementing a computer system is the technology barrier between system designer and application specialist. The more the specialised knowledge can be diffused between the two, the more usable will be the system.
- (d) Be aware of the techniques for designing human/machine interfaces. This is a critical area in systems design and it would be beneficial if systems designers were aware of current research and techniques.

The Specialised User (for example, the stress analyst, kinematician or materials engineer).

50. If a product is complex, the designer's solution is only a first approximation which is refined by specialised analysis. Presumably, an aim of the integrated CAE system is to transfer expertise from the specialist to the analytic model. However, current CAD sub-systems with the exception of draughting systems, are not easy to use and require a good deal of training and experience if a high degree of confidence is to be placed in the results. It seems likely that for several years there will be a place in the design function for specialised users. The specialised user should:

- (a) Be aware of the theoretical bases of the specialised sub-system so that the results may be critically appraised.
- (b) Know the sub-system thoroughly so that all its facilities and options may be used. This results in a more creative and productive utilisation. For instance, in a finite element system, the overheads of data preparation and processor time may be often considerably reduced by a thoughtful use of the facilities offered.
- (c) Have a fair knowledge of other sub-systems used so that advantage may be taken of them where convenient and correct data supplied for them where required. An example is in the use of finite element packages; shape description or draughting systems may often be conveniently used to set up meshes interactively.
- (d) Have a formal training in the specialisation. It may well be, as has been previously mentioned, that as systems become more sophisticated, an increasing amount of expertise is transferred from human to machine. However, even if all the analytic work were done by the computer, it is unlikely that the final "optimised" design solution would be accepted without demur. Also, factors other than functional aptness – e.g. aesthetic appeal and novelty value – must be taken into account and it is unlikely that CAD systems will be able to do this in the immediate future.

The Naive User (for example, the rank and file designer).

51. Very little need be known about the internal workings of either hardware or software. Packages will be used in an uncritical way to find approximate design solutions so that the process of design iteration may be carried out more rapidly than at present. This class of user will probably employ a subset of the facilities provided so that training

time may be minimised.

The naive user should:

- (a) Have a fair knowledge of the local analytic modelling system — e.g. finite element analysis, mechanism analysis, machine element analysis. These will be used as an adjunct to the normal design process.
- (b) Be able to use databases so that standards and materials may be selected in an appropriate and economic way.
- (c) Be able to use draughting systems and shape description systems. Engineers generally communicate ideas graphically. Although most geometric modelling systems are difficult to use without a good deal of experience, it would be worthwhile for a designer to be able to use such a system fluently for viewing and sketching purposes. It may well be that as more experience is gained in the design of these systems, their use will become as easy as that of computer draughting packages.

Training Requirements

52. The training of each of the three categories of user will be distinct. The systems designer probably requires post-graduate training. However, the Computer Users' Year Book 1981 does not list any suitable courses. This may have now remedied but if not, it is certainly an area that Universities might explore, particularly since Master's Degree programmes in CAD appear to be quite common in the USA (Ref 4).

53. The specialised user will presumably have a formal qualification in the specialisation. Since most scientific courses these days contain an element of computing, this should be sufficient. This type of user will obtain the rest of the training either by experience or by attending a software suppliers course.

54. The difficult area is in the training of the naive user. As this type of user will use most of the elements of the system, the training should be broad and descriptive in nature rather than detailed. The topics to be covered are listed in Appendix A which could form the basis of a CAD module on all engineering courses.

APPENDIX A

Computer Aided Design Curriculum

1. This is a fairly comprehensive treatment of CAD topics based broadly on the TEC approach. Any CAD course should contain the bulk of the topics; in advanced courses topics should be treated in a more detailed and analytic fashion and more effort should be devoted to the integration of CAD with other functions in the firm.
2. It is important, because of the rapidly changing nature of this and other modern fields, that some slack should be left in syllabi for the injection of new material so that courses may respond rapidly to advances in technology.
3. It may be necessary in topic area D to dilute considerably the material for TEC and other non-degree courses, since much of the material is highly mathematical. However, some of the objectives may be attained by using a descriptive approach.
4. Pre-requisites for such a curriculum should include a basic design course; a general computer appreciation course and preferably a course in elementary programming so that some practical work may be carried out in designing small analytic models.
5. A further consideration is how this curriculum dovetails with cognate curricula such as for CAM and computer-aided management. Some attempt has been made to do this explicitly.

Computer Aided Design

Aims:

To give the student:

- (i) an appreciation of the ways computers may be used in design;
- (ii) a general knowledge of the hardware and software used in computer-aided design;
- (iii) a broad idea of the theoretical bases of the computer graphics applicable to computer aided design;
- (iv) the ability to specify the computer aided design system which is appropriate for a given need.

Content:

In the following scheme, topic areas are prefixed by a capital letter, general objectives by a non-decimal number and specific objectives by a decimal number. General objectives give the teaching goals and specific objectives the means by which the student demonstrates his attainment of them. All the objectives should be understood to be prefixed by the words: "the expected learning outcome is that the student".

A CAD Systems Organisation and Topology

- 1. Appraises the structure and purpose of CAD systems.
 - 1.1 Describes in detail the design process.
 - 1.2 Relates the individual elements of the design process treating each as a separate sub-system with well defined interfaces.
 - 1.3 Determines which elements of the design process may be improved with computer aided and appraises the extent of the improvement in productivity, convenience and organisational efficiency which results.
 - 1.4 Discusses the properties of human/machine interfaces and their systematic and efficient construction.
 - 1.5 Compares the various means of financing CAD systems including use of a bureau, leasing and buying outright.
 - 1.6 Examines the effects of CAD and the roles of designer and draughtsman.

B CAD Hardware Considerations

- 2. Appraises the use and action of CAD hardware with reference to function, speed and cost.
 - 2.1 Distinguishes between refresh tubes, direct view storage tubes and raster screens.
 - 2.2 Describes the operation of electrostatic and dot matrix hard copy units.

- 2.3 Describes the action of drum and flat-bed plotters.
- 2.4 Distinguishes between the various types of input devices including bitpads, digitisers and cursor control devices, such as joysticks, thumbwheels and lightpens.
- 2.5 Compares various types of computer used with CAD systems including dedicated desktop machines and time shared systems.
- 2.6 Describes the action of other current devices.

C CAD Software Considerations

- 3. Distinguishes the various software sub-systems which may be used in a comprehensive CAD system.
 - 3.1 Describes the purpose and structure of shape description systems and reviews a cross-section of current systems.
 - 3.2 Describes typical analytic models taking as examples a practical finite element analysis package and other sub-systems locally appropriate.
 - 3.3 Reviews computer aided draughting systems in general and analyses a typical system in detail.
 - 3.4 Describes the organisation, structure and use in CAD of engineering databases.
 - 3.5 Relates the output from CAD functions to other parts of the integrated computer aided engineering system such as CAM.
 - 3.6 Describes the action of other current software.

D Elements of Computer Graphics

- 4. Describes the theoretical basis of computer graphics used in CAD systems.
 - 4.1 Reviews current thought on standards in computer graphics; for example the core and GKS standards.
 - 4.2 Describes the structure and facilities of typical graphics systems such as GINO-F.
 - 4.3 Appraises the data structures used in CAD programs.
 - 4.4 Describes the principles of clipping, windowing, hiddenline and surface removal and two- and three-dimensional transformations.
 - 4.5 Compares the various methods of representing three-dimensional solids and surfaces in three dimensions.
 - 4.6 Describes methods of obtaining realism in computer graphical models including colour, textures, specular reflection, shading, stereoscopy and holographic developments.
 - 4.7 Describes other current techniques.

APPENDIX B

Help available through the West Midlands Regional Office Departments of Industry and Trade (covering also the British Overseas Trade Board and the Department of Energy)

1. The information below is abridged and covers only the major activities of the Office. It is for guidance only. Full details are available on request (see paragraph 26 for contacts). If you desire other forms of help please ask – we may still be able to provide it.

DEPARTMENT OF INDUSTRY

2. Under all schemes, assistance cannot be retrospective so early contact by potential applicants for help is desirable. The "Additionality" concept is applied in most, but not all schemes. This means that the Department must be satisfied that its support will cause the work to be enhanced in some way that could not occur without support, eg faster, on a larger scale or at all. In most cases assistance is selective as funds are limited.

Research, Development, New Technology and Technology Transfer

3. The Department's Industrial Research Establishments are prepared to carry out work for industrial organisations on a contract basis with full commercial security.

4. Soundly based industrial research and development projects can be supported under a general scheme covering any stage up to and including the launch of new or significantly improved products and processes. Grants can be made of up to 33 1/3 % of eligible costs; or pre-production orders can be placed for user-evaluation equipment, or contracts can be placed offering 50% of eligible costs to be recovered later by a levy on sales. The projects should cost over £25,000 but small firms may be supported in smaller projects. Projects costing less than £200,000 are likely to be appraised by technologists based in this office.

5. A wide range of projects for the introduction of microelectronics in the products or processes of any sector of manufacturing industry can be supported by grants of up to 33 1/3 % of eligible costs under the Microprocessor Application Project (MAP). A part of this scheme, MAPCON, may reimburse the costs of consultancy (up to £3,000) on the feasibility of using microelectronics.

6. The Department will subject applications under

paragraphs 4 and 5 above to a technical/commercial appraisal. Applicants who are looking to other institutions to help finance their project may elect to use the Joint Appraisal Scheme. Under JAS the Department's appraisal is made available to the financial institution nominated by the applicant.

7. Makers of microelectronic equipment (rather than incorporators of such equipment) may be supported under the Microelectronics Industry Support Programme (MISP).

8. Several forms of support are available to encourage wider use of computer aided engineering (CAE). A CAE data service operated for the Department by the Institution of Electrical Engineers aims to provide a service on all aspects of CAE. First time users of computer aided design and test equipment may obtain assistance towards purchases of CAE equipment (other than production machinery) under the CADTES scheme. Companies in the mechanical and electrical sectors may receive support up to £2,000 towards CAE feasibility studies and may take part in seminars for senior management, hands-on experience of CAE methods at Practical Experience Centres and various in-depth courses (CADCAM scheme). Companies in the electronics industry may receive similar support but extended to include computer aided testing (CADMAT scheme). The Department may also support companies willing to run CAE demonstration units.

9. Companies in the fibre optics and opto-electronics industries are particularly invited to apply for support. For development projects support will be largely as described in paragraph 4 above. For the provision of new production facilities support will be as described in paragraph 15 below.

10. To encourage the introduction of robots a free advisory service and supported consultancies are available. Financial support can be given to schemes for the introduction of robots or for their manufacture or development.

11. Companies proposing to install flexible manufacturing systems may obtain support of up to £50,000 for a feasibility study followed by a grant of up to 33 1/3 % towards development and capital costs.

12. The Department can provide information on licensing

procedures to companies which, under the British Telecommunication Act 1981, wish to supply new telecommunications equipment or services using the network of British Telecom.

13. Help can be given by putting companies in touch with local expertise and with national sources of information on technological and other matters. This service is free. In particular help can be given on technology transfer and on Information Technology subjects. Contact can be made with the Technology Advisory Point and with the advisory and information services of Government Research Establishments.

Modernisation and/or Expansion of Production Facilities

14. Under the Manufacturing Advisory Service (MAS) and the Design Advisory Service (DAS) most manufacturing units may have free consultancies.

15. Assistance under Section 8 of the Industry Act 1972 is available for major new investment by manufacturing industries in plant, machinery and associated buildings anywhere in the UK. Projects must be commercially viable, in the national interest, and involve at least £0.5M, including working capital. The amount and terms of assistance are negotiated as the minimum necessary to bring about completion of the project. "Additionality" must be demonstrated (see paragraph 2 above).

16. Information can be given on financial assistance available in the Assisted Areas of the UK; this includes help from both UK Government and EEC sources. There are no Assisted Areas in the West Midlands although Dudley has an Enterprise Zone.

17. Funds may be available to support projects which create employment in areas where there have been large scale closures in the coal and steel industries. In the West Midlands these are in Dudley, Stoke-on-Trent and Wolverhampton.

Small Firms

18. The Department of Industry's Small Firm's Service

provides information on all aspects of running or setting up a small business. It is backed by a Counselling Service which uses experienced business men to provide practical management advice. The first session with a Counsellor is free but subsequent consultations attract a modest fee.

Schools Industry Liaison

19. It is vital to improve the knowledge of industry and the realisation of its importance among school children and their teachers. Much more needs to be done and anyone interested can be given information on activity in this field within the Region. Support, including perhaps Financial help, may be given to certain activities. A number of projects are looking for speakers from industry; engineers are especially needed.

DEPARTMENT OF ENERGY

20. General information on energy conservation and on local meetings of Energy Managers is available.

21. The Energy Survey Scheme allows for an initial subsidy of up to £75 towards the cost of a one-day consultancy. A 50% subsidy may be available for energy audit work.

22. Under the Energy Conservation Demonstration Project grants of up to 25% may be given towards the costs of a project plus up to 100% of the cost of monitoring and publicising the energy savings achieved.

23. Help is available companies who wish to replace oil or gas-fired "Industrial equipment" by coal-fired "equipment", or to convert existing "equipment". Included are boilers, furnaces, kilns and ovens.

24. Market and technical information is available on offshore oil and gas exploration and exploitation.

DEPARTMENT OF TRADE

Exports

25. This office acts as the main point of contact for

exporters and potential exporters in the West Midlands Region seeking assistance and advice. It provides the full range of export and trade promotion services available through the British Overseas Trade Board. These include Trade Fairs, Outward Missions, Market Advisory Service, Export Intelligence Service and general market information. The services are carried out in close co-operation with the Commercial Departments of the 190 British Embassies, High Commissions and Consulates abroad, who are able to provide expert knowledge of prospects in their local territories for British goods and services.

CONTACTS

26. These notes are for guidance only.

For full details about: — Please contact: —

Paragraphs 3-11, 13 & 14 Dr W D G Bennett Ext 547

Paragraphs 15-17 Mr J N Garnett Ext 504

Paragraphs 12, 19-24 Mr A M Mendoza Ext 539

Paragraph 25 Export Enquiries Ext 517/518

Paragraph 18 Small Firms Centre Freefone 2444

West Midlands Regional Office
Departments of Industry and Trade
Ladywood House
Stephenson Street
BIRMINGHAM B2 4DT
Telephone 021-632 4111

This office covers the countries of Hereford & Worcester, Shropshire, Staffordshire, Warwickshire and the West Midlands. If you are situated elsewhere, you should contact the Regional Office serving your area. However, letters of enquiry will if necessary, be forwarded to the appropriate office.

SEPTEMBER 1982

For Small Firms Centre enquiries only, Freefone 2444 is available.

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APPENDIX C

A Short Glossary of Terms Used in the Paper

CAD (Computer Aided Design)

Use of a specialised interactive computer system to aid the design process from the conceptual stage to the production of a working drawing. Functions may include some or all of the following: –

Construction, viewing and alteration of the form of the product.

Selection of materials

Stressing.

Performance calculations.

Production of drawing.

CAE (Computer Aided Engineering)

Use of several sub-systems (including CAD and CAM) in an integrated way to perform all engineering functions from design specification to the production of a saleable part.

Functions may include: –

Design and prototype production.

Manufacture: Planning, sequencing, tooling.

Automatic inspection.

Drawing production.

Costing and purchasing.

At the moment, there are only a few firms which approach this sort of integration but it seems probable that there will be many more in the next ten years.

CAM (Computer Aided Manufacturing)

Use of a specialised interactive computer system to aid the manufacturing process. Typically, the machining of the part is simulated in detail on a graphics terminal. Rough cutting and accurate machining is performed and the information generated may be used to produce a numerical control tape or to drive the machine tool directly. Currently, the user supplies information regarding cutter size and speeds and feeds but it is envisaged that this may soon be done automatically.

Databases

In the past, data files were specific to particular programs. This was wasteful of effort and error prone. If bulk data is kept as an entity separate from the programs accessing it, and an accessing mechanism interposed between programs and the data so that programs are independent of the physical means of data storage and representation, it is referred to as a database. Candidates for database applications are materials and standards.

Finite Element Analysis

A system for calculating stresses and displacements of parts subject to loading. The part is built up by the user from a standard set of elements and the loading conditions supplied. Resulting displacement and stresses may be displayed graphically or numerically. The method is well developed, is widely used and is also suitable for problems involving dynamics, thermal stresses and flow.

Geometric Modelling

The holding of the physical properties of the object within the computer in numerical form. Although strictly speaking, the term only applies to description of the shape of the object, other physical properties such as tolerances, surface finishes and materials may be held in the model. The geometric model may be used directly for the calculation of weights, volumes and surface areas and the most useful systems permit the object to be viewed and changed interactively. Many current systems are difficult to use but development in this field is rapid.

Graphics Screens

There are three popular types of screen.

- (i) Refresh screens – the picture is drawn directly from point-to-point with the electron beam and refreshed, typically 50-60 times per second.
- (ii) Direct view storage tubes – the picture is drawn directly but is maintained by means of one or more "flood guns" which obviates the need for refreshment.

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- (iii) Raster screens — the screen is scanned similar to a TV tube and the beam is modulated at precisely timed intervals so that selected spots may be lit or not. The picture is composed of a rectangular array (up to 1024×1024 currently) of picture elements or 'pixels'.

Each has its own advantages but probably the best for CAD use is the raster screen which is comparatively cheap and may be used for full colour applications.

Hardcopy Units

These produce a drawing of what is currently on the screen. There are various types including electrostatic, xerographic and impact printers.

Input Devices

There are various types in common use. They are a means of pointing to a particular position on the screen, the point of interest being shown often on the screen by a crosshair cursor. Typical devices are: —

- (i) Light pens: hand held devices enabling the user to point directly to a feature of interest on the screen.
- (ii) Thumbwheels and joysticks: enable the user to move the crosshair cursor to a point of interest and to enter its position to the computer.
- (iii) Bitpads: flat plates used in conjunction with a hand held stylus. Often the plate is covered with an overlay sheet with specific areas devoted to particular functions. These "menus" may then be "picked" with the stylus.

Plotters

Often plotters used with CAD systems are of the flatbed type where the drawing is performed on a horizontal plotter usually up to AO size and often with a variety of pen thicknesses and ink colours. Another common type of plotter is the drum plotter which can produce drawings of longer length but usually of lower precision than the flatbed.

APPENDIX D

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FEU Publications

Computer Aided Design in FE is one of a number of FEU publications intended to inform teachers and others and to stimulate professional discussion about matters of concern to the Further Education Service.

Further information about these research projects can be obtained from the Further Education Unit, Room 5/89, Elizabeth House, York Road, London SE1.
Tel. No. 01-928 9222 Ext 3307/2410.

Another FEU publication in the Occasional Paper Series is:

Microelectronics in FE: some personal perceptions. October 1981. This report by Dr Ken Dean, Principal of South East London College describes from a personal point of view a fast moving field of activity.

The document should help, in part at least, the education system to appreciate the nature of accelerating technological change, which is distorting and elongating the conventional spectrum of skills that are required by society.

Copies of *Microelectronics in FE* (which are free of charge) are obtainable, while stocks last, from the Publications Despatch Centre, Department of Education and Science, Honeypot Lane, Canons Park, Stanmore, Middlesex HA7 1AZ. Tel. No. 01-928 2366 Ext. 503.

The FEU has also a number of research projects (RP's) under way relating to microelectronics:

- RP 55 Computer literacy in vocational preparation schemes.
- RP 56 Staff development associated with teaching and learning application of micro-computers in FE.
- RP 59 Review of microelectronics in FHE.
- RP 65 Robotics – a curriculum module for technicians.
- RP 80 Computer assisted profiling.
- RP 87 Computer-aided profile assessment and curriculum design across a college of FE.
- RP 90 Staff development micro-computing.
- RP 94 Computer appreciation.
- RP 104 Introduction of computer studies and 'hands on' experience into lower level courses.
- RP 106 Word processing, learning packages for teachers and students.
- RP 108 Training in micro-computer use for 16-19 FE students.
- RP 118 Computer Literacy for shipping management.
- RP 119 Robotics – implications for FE curricula.
- RP 124 New Office Technology (background paper).